INNOVATIVE
TECHNOLOGY
SUMMARY REPORT
for the
Large Scale Demonstration and Deployment Project of Hot Cells

IDENTIFICATION OF CONCRETE EMBEDDED COMPONENTS USING GROUND PENETRATING RADAR

Demonstrated at
West Valley Demonstration Project
West Valley, New York

WVNSCO
West Valley Nuclear Services Company

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Purpose of this Document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environment management problem. They are also designed for readers who may recommend that prospective users consider a technology.

Each report describes a technology, system, or process that has been developed and tested with the funding from the DOE Office of Science and Technology (OST). A report presents the full range of problems that a technology, system or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

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SECTION 1
SUMMARY

Technology Summary

Preparing to decontaminate radioactive hot cells often requires creating new penetrations by drilling (core boring) into hot cell shield walls. Frequently, shield walls contain embedded components, like process piping, rebar, and conduit. These embedded components must be accurately identified before core boring can be performed safely.

At DOE sites with older facilities like those at the West Valley Demonstration Project (WVDP), where systems associated with facility operations have been de-energized for many years, embedded components are identified by reviewing engineering and construction drawings. This method is employed because using electrical tracer signals to identify embedded components is known to fail when signals pass through components in contact with other metal objects like rebar. If drawings reviewed to identify components are out-of-date, this also increases the potential for inaccurately identifying components that may be embedded in concrete.

Ground Penetrating Radar (GPR) is a synchronized radio transmitter and receiver system that uses ultra high frequency radio waves (microwaves) to detect objects in the subsurface. This type of radar has been used in the commercial sector to identify objects embedded in materials like concrete for more than two decades. Advancements in computerization of this technology over the last ten years have made it possible to produce high-resolution, three-dimensional volumetric images of areas surveyed using GPR. This has significantly increased the efficiency and reliability of using GPR to examine concrete structures like bridges and roadways. Although using GPR to detect objects embedded in concrete at depths greater than 2-ft is not well documented, it has been postulated that GPR can detect and identify objects embedded in concrete at depths greater than 3-ft. (1) (2) (3) Thus GPR may be suitable for use as a tool to identify components embedded in hot cell shield walls. Figure 1 shows how GPR can be used to survey a location along a surface like a shield wall.

Figure 1. GPR Survey

Demonstration Summary

Demonstrations discussed in this report were conducted using a GPR system known as a Subsurface Interface Radar (SIR®) system. This system was used to survey concrete surfaces at a series of locations where the presence of embedded components could be confirmed, either through visual inspection or by comparing survey results with engineering drawings. Survey testing was carried out at 19 different locations where concrete shield walls varied from 3-ft to 5-ft in depth. Eight of the surveys performed were conducted in a newly constructed (currently non-radioactive) facility. The remaining surveys were conducted in locations where hot cell decontamination is being carried out. Figure 2 shows survey testing being preformed in the newly constructed facility using a SIR® System-2 unit.

GPR surveys conducted using the SIR® System-2 unit accurately identified components embedded in concrete shield walls up to 4-ft thick. Accuracy diminished at depths greater than 4-ft thick, although it may be possible to increase accuracy at depths greater than 4-ft by using a different antenna (one with a lower frequency) or by setting the GPR unit with a specific dielectric constant before surveying a concrete shield wall. Overall, GPR proved to be a useful tool for enhancing the safety of core boring operations up to concrete depths of 4-ft.

Figure 2. Survey Test using a SIR® System-2 Unit

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Licensing

Federal Communications Commission, Attn: UWB Coordination, Frequency Coordination Branch, OET
445 12th Street, SW, Washington, D. C. 20554

Permitting
No permits involved.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

Standard methods used to detect embedded components often fail to identify embedded components. This increases the potential for risks to worker safety during core boring operations. GPR is a non-invasive, inherently safe technology that produces cross-sectional images of subsurface objects in real-time. Data collected during field surveys performed with GPR equipment can be used in combination with computer software to produce three-dimensional volumetric images. These computer generated images can be used to reveal the location of embedded components that otherwise may be impossible to identify with requisite accuracy.

Standard surveys using GPR are typically conducted from the surface of the ground to depths of up to 100-ft in low conductivity materials such as dry sand or granite. Clays, shale and other high conductivity materials including concrete may attenuate or absorb GPR signals, greatly decreasing the depth of the penetration to 3-ft or less. Commercially available GPR systems operate over the frequency of 10 Megahertz (MHZ) to 1000 MHZ. The lower frequencies provide better penetration but poor resolution. Higher frequencies give poor penetration, but good resolution. Commercially, GPR surveys are used for many purposes including:

- Archaeological Studies
- Profiling Lake Bottoms
- Mines and Minefield Clearing
- Detecting Ordnance
- Detecting Hazardous Waste

System Operation

GPR systems work by transmitting pulses of ultra high frequency radio waves (non-ionizing radiation consisting of microwave electromagnetic energy) into the subsurface through a transducer or antenna. Transmitted energy that reflects off of various objects in the subsurface is received by the antenna. Reflected waves received by the antenna are then stored in the digital control unit. Information stored in the digital control unit can be viewed in the field using a display monitor, or transferred to a computer for advanced imaging and further analysis after the field survey is completed.

GPR is a ready off-the–shelf technology. The equipment is self-contained for field use and is manageable by a single individual. Based on the application, the operator chooses from a selection of antennae, with variable power strengths for the specific substrates to be imaged. No site-specific requirements or equipment modifications are needed because GPR does not produce any radio signal interference and is occupationally safe to use. The only requirement for using GPR is that the surface to be scanned is smooth and free of obstructions. If GPR is going to be used in radiologically contaminated areas, it is recommended that the areas to be radiologically scanned be free of contamination or covered to prevent contamination of the specialized equipment.

From a field operations standpoint, GPR is reasonably easy to use given the appropriate training. Operator training typically consists of a 40-hour classroom and hands-on proficiency demonstrations. Therefore, the field operator could be a manufacturer trained and qualified technician or skilled worker. From a data analysis and evaluation standpoint, the GPR field measurement output data is very complex. For simple applications, an experienced operator working with engineers and plant prints may be able to identify the location from the visual output of GPR unit. More complex scenarios and areas require analysis by special computer software and evaluated by experienced professional geologists.

SECTION 3
PERFORMANCE

Demonstration Plan

The main objective for demonstrating GPR technology at the WVDP was to investigate use of this technology as means of locating and identifying embedded components that are typically found in shield walls, including piping and rebar. Plans for demonstrating GPR technology were structured to determine the accuracy and reliability of using GPR to locate components embedded in shield walls of hot cells where facility decontamination and dismantling activities are being conducted.

Using site safety requirements and work control processes as the starting point for plan development, a three-step test plan was prepared to demonstrate GPR technology in a series of locations, beginning with scans of simple concrete surfaces and progressing to demonstration at specific points along reinforced concrete walls and floors near hot cells now undergoing decontamination.

The first stage of the test plan for demonstrating GPR technology involved using a Subsurface Interface Radar (SIR®) System-2 Radar unit at the vendor's facility, GeoModel Inc., to confirm that the unit could be used to identify embedded piping in concrete at depths similar to those to be tested at the WVDP. No special set-up was required to test the unit other than to select a smooth surface area for testing. The surface tested was a 18-inch thick segment of a concrete floor with an intermediate layer of subsurface soil with a clay base. During this initial stage of testing, the radar unit was operated by two personnel, a support person to move the radar antenna over the examination area and a qualified operator to help direct the operator during the demonstration. As the unit was being tested, the operator was able to identify rebar and embedded piping in the concrete floor consistent with vendor, manufacturer and published scientific literature.

The second stage of the test plan involved using the SIR® System–2 Radar unit to examine eight different locations in a facility under construction at the WVDP site, the Remote-Handled Waste Facility (RHWF). This facility was selected for demonstrating GPR technology because it is possible to use engineering drawings of the RHWF to confirm the location of embedded components and because it is possible to visually verify embedded components in test locations. Testing was conducted by marking out a grid on the surface to be scanned, numbering the grid for identification of both an x- and y-axis, and scanning marked points on the grid at a rate of two-inches per second with the 900MHz antenna every six-inches in both X and Y directions. Each location was scanned three times to produce a three-dimensional image of the test location. A summary of the locations scanned and test results are provided in Table 3.1 GPR Cold Test Surveys.

Table 3.1 - GPR Cold Test Surveys

Test Area	Area Features	Component Examined	GPR Result
Cell Floor	3-ft concrete floor	2-in double-walled steel drain pipe	Pipe identified at depth of 1-ft. - located as shown on construction drawing.
Cell Floor	Drain pipe exit sloping to lower level	Drain pipe	Pipe identified. Depth unclear. - located as shown on construction drawings.

Table 3.1 - GPR Cold Test Surveys

Test Area	Area Features	Component Examined	GPR Result
Pre-filter Plenum	Wall containing 13-in diameter light gauge metal duct	Front face of plenum	Plenum identified at depth of 2-ft - located as shown on construction drawings.
Pre-filter Plenum	Wall containing 13-in diameter light gauge metal duct	Side face of plenum	Plenum not identified - According to construction drawings, plenum direction is away from test face, outside range of radar detection.
Airlock Wall	3-ft concrete wall - penetrations at 1-ft & 2-ft.	2-ft wide area on wall	Two voids identified - Voids visually confirmed.
2nd Floor - Operating Aisle	Segment of wall	Wall area 4-ft from shield window	Solid wall - Steel window frame not identified.
3rd Floor - Airlock Wall	Segment of wall	Penetration 1.5-ft from wall	Penetration identified - location visually confirmed.
Outdoor Block	Outer wall	Void section at 2.5-ft in outer wall	Void identified at 2.5-ft - location visually confirmed.

The third and final stage of the test plan for demonstrating GPR technology involved using the SIR® System–2 Radar unit at locations where decontamination activities are being conducted (as shown in Fig. 3). In preparation for testing walls and floors in these locations each area was evaluated to confirm the core bore history of the area; ease of physical access by the radar operator(s); potential future use of the area for decontamination operations and support; available surface area for scanning; physical smoothness of the scanning area; physical interferences, such as piping, hangers and structures; and radiological conditions. Based on these criteria, 11 test areas were selected for actual demonstration. In preparation for using the SIR® unit in each test location, identified areas were surveyed for radiological contamination, decontaminated as needed to prevent unit contamination, and covered with smooth matting to ensure unit performance during scanning. As with tests carried out in the RHWF, area floors and walls were marked with test grids and scanned to produce three-dimensional images of the test areas. A summary of the locations scanned and initial test results are provided in Table 3.2. - GPR Hot Test Surveys.

Table 3.2 - GPR Hot Area Test Surveys			
Test Area	**Area Features**	**Component Examined**	**GPR Finding**
XCR (XC-1/XC-2 ceiling)	Cell ceiling - near wall	Embedded piping	Numerous embedded components & anomalies identified. - line identified corresponds to 30 small pipes; anomalies correspond to five embedded pipes shown on drawings.
XC-1 Shield Hatch	5-ft thick concrete	Shield hatch	Numerous embedded components identified. - locations & depths indicated consistent with drawings.
XC-2 Shield Hatch	3-ft thick concrete	Shield hatch	Numerous embedded components identified. - locations & depths indicated consistent with drawings.
Extraction Sample Aisle	3-ft thick concrete	Sample lines - enclosed in metal box	Five anomalies noted on area grid. - locations consistent with internal supports in area.
Extraction Sample Aisle - XC-2 north wall	3-ft thick concrete	Sample lines - enclosed in metal box	Four anomalies noted on area grid. - locations consistent with internal supports in area.
Extraction Sample Aisle - Airlock - upper north wall	3-ft thick concrete	Wall area - void space	No anomalies noted. - locations consistent with engineering prints
Extraction Sample Aisle - Airlock - lower north wall	3-ft thick concrete	Wall area - void space	1.5-ft boomerang-shaped anomaly. - Prints indicate void area - anomaly could be extraneous steel or higher density concrete
Aisle/ XC-1 north wall	5-ft thick concrete	Wall area - void space	Two anomalies noted. - Prints indicate void area - anomaly could be extraneous steel or higher density concrete
Upper Warm Aisle - XC-1 south wall	5-ft thick concrete	Wall area - void space	Anomaly noted. - Prints indicate void area - anomaly could be steel reinforcement or embedded pipe hangers.

Table 3.2 - GPR Hot Area Test Surveys			
Test Area	**Area Features**	**Component Examined**	**GPR Finding**
Upper Warm Aisle - XC-2 south wall	3-ft thick concrete	Wall area - void space	Anomaly noted. - Prints indicate void area - anomaly could be steel reinforcement or embedded pipe hangers.
Upper Warm Aisle - XC-3 south wall	3-ft thick concrete	Wall area - void space	Anomalies noted. - Prints indicate void area - anomalies could be structural steel

Results

Based on the WVDP review of the GeoModel report on test areas and comparison with site knowledge and prints, results from demonstration of GPR at the WVDP can be summarized as follows:

For 3-ft thick concrete walls: The radar clearly identified areas free from embedded components, areas with known embedded components, and areas with anomalies that may be obstructions such as steel plate but are not shown on the "As-Built" prints. The radar also identified anomalies near the interior of the shield walls at depth up to 3-ft. These appeared to be pipe hanger anchors and plates that support hot cell interior process piping, tanks, and equipment.

For 4-ft thick concrete walls: The radar clearly identified areas free from embedded components. Detection capability appears to be limited to a depth of 4-ft using a 900-MHZ antennae.

For 5-ft thick concrete walls: The radar unit proved to be ineffective at identifying components embedded at depths greater than 4-ft using a 900-MHZ antenna. A 400-MHZ antenna may be considered for use with walls up to 5-ft thick. However, image resolution may be reduced at this lower frequency.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

High levels of radiological contamination in hot cell shield walls limit the types of technologies that can be used to identify embedded components to those that are non-invasive. Therefore, methods of identifying embedded components, such as drawing review or electronic signal tracing, were considered as the only viable alternatives for identifying embedded components in hot cell shield walls.

Technical Applicability

GPR can be used in a variety of settings. The major advantages of using GPR to identify embedded components can be summarized as follows:

- GPR is an inherently safe technology that produces a signal less than 1/1000th of the power of a mobile phone.
- GPR is a non-destructive technology easily deployed in a variety of settings.
- GPR units are designed to prevent transmission of unwanted radio interference or signals.
- A GPR antenna can be operated remotely with a 100-ft cable.
- Teflon-like coating on contact scanning surface of a GPR antenna is easy to decontaminate with cloth wipes.
- Selecting specific dielectric constant for materials scanned can improve survey results.
- Harness for the GPR unit ergonomically balances equipment for operator during use.

Patents /Commercialization/Sponsor

The GPR can be used in a variety of industrial settings, including nuclear power plants, where safe concrete core boring is required.

SECTION 5
COST

Methodology

Information used to develop a cost estimate for using GPR as a means of detecting embedded components were provided by the vendor that demonstrated this technology at the WVDP, GeoModel Inc. The unit used to perform the demonstration, the SIR® System–2 Radar system, is used commercially for a broad range of environmental, geotechnical, geological and engineering applications. Major cost components associated with using this radar system form the basis for analyzing costs and preparing the cost estimates presented here.

Two estimates are provided. The first estimate defines the key components used to analyze costs for demonstrating GPR technology, and presents the cost estimate developed by analyzing these cost components. The second estimate defines the key costs components used to analyze the costs of productivity losses caused by making repairs and re-coring, and presents the cost estimate developed by analyzing these cost components. Since GPR is an enabling technology, the cost components used to prepare the second estimate were developed for comparative purposes. Both estimates were prepared by the United States Army Corps of Engineers (USACE), which provided cost analysis support for this LSDDP.

Cost Analysis

The total cost for demonstrating GPR technology may be thought of as a sum of the following cost components:

Investigating/Design/Permitting: Costs for preparing permits that may be required to deploy a technology. These costs include the time needed to prepare, review, and approve a permit before work can begin, and are dependent on the level of effort needed to prepare and obtain approval.

GPR Mobilization / Demobilization: Costs associated with mobilizing a GPR unit. These costs are dependent on mileage, mode of transport, Per Diem and associated labor. For the purposes of preparing the estimate, it has been assumed that it would take the vendor 1 day to mobilize and demobilize at a site.

Data Acquisition: Costs associated with gathering data at the site by the vendor. These costs can be defined as the sum of the total labor, equipment and Per Diem.

Field Support: Costs associated with facility support. These can be defined as the sum of Health Physics, Radiation Technician and Equipment Operator labor needed during the data acquisition phase.

Analysis/Reporting: Costs associated with preparing a written report of test results, including 3-D graphics of the test areas and descriptions of all embedded piping, rebar and any other obstructions that may interfere with concrete boring operations. These costs can be defined as the sum of the total labor.

Table 5.1 - Summary Estimate for Using GPR Technology

Cost Components	Man-hours	Labor cost	Equipment cost	Misc. Cost	Totals
Permitting				$1000	$1000
Mobilization & Demobilization	16	$1300	$140	$260	$1700
Data Acquisition	40	$3200	$1280	$520	$5000
Field Support	120	$9800			$9800
Analysis & Report Writing	40	$3200			$3200
Total Costs	216	$17,500	$1420	$1780	$20700

Repair and Re-coring Cost Components and Total Cost Estimate

The total cost for repair and re-coring may be thought of as the sum of costs for repairing and re-coring a section of a shield wall, as would be required if an unidentified embedded component were hit during core boring operations. The cost components defined here reflect a range of activities that may need to be performed after hitting an embedded component during core boring operations. The cost estimate prepared using these components corresponds to making repairs and re-coring at a minimum of three locations surveyed at the WVDP.

Drill Extraction and Associated Delays: Costs for extracting a drill after hitting an unidentified component. These costs can vary significantly. For comparative purposes, an 8-hour delay was assumed for an entire work crew, including oversight and rad technicians.

Drawing Review to Identify a New location: Costs for conducting a drawing review. For comparative purposes, a minimum of four hours were assumed to conduct an engineering review to identify a new location for re-coring.

Grouting and Pipe Repair: Costs for making repairs to safely continue work in the area. Although it is impossible to identify the range of problems associated with damaging processing pipes or electrical conduits, the costs and level of effort needed to restore functions in an operating plant could be very expensive. For most decommissioning projects, the need to restore functionality is reasonably unlikely because the facility and equipment is generally de-energized and deactivated. Discussions with facility managers revealed that it may be necessary to shutdown operations to complete grouting of an area after failed core boring. For estimating purposes, a 4-hour best-case scenario was assumed for an entire work crew, including oversight and radiation technicians.

Re-coring: Costs associated with re-coring. For estimating purpose, 8 hours were assumed for an entire work crew, including oversight and radiation technicians.

Table 5.2 - Summary Estimate for Repair and Re-coring Operations

Cost Components	Man-hours	Labor cost	Equipment cost	Misc. Cost	Totals
Drill extraction & associated delay	144	$12,000	$300	N/A	$12,300
Drawing Review	48	$1,080		N/A	$2,160
Repairs	72	$6,000	$150	N/A	$6,150
Re-coring	144	$12,000	$300	N/A	$12,300
Total Costs	408	$31,080	$750	N/A	$32,910

Cost Conclusions

The total estimated cost for demonstrating at the WVDP, $20,700, compares favorably with the projected cost that would be incurred for repairs and re-coring, $32,910 for three locations at the WVDP. Comparison of both estimates can be used to determine the value of using GPR as a personnel safety enhancement to core boring operations. Although not considered as part of the total estimate, additional cost savings related to reduced potential exposure to occupational or environmental hazards may be realized if GPR is used to detect embedded components.

SECTION 6
OCCUPATIONAL SAFETY AND HEALTH

Required Safety and Health Measures

GPR equipment is inherently safe to use. The risk of exposure to radiological hazards using GPR is no greater than that associated with entering an area posted as a radiological buffer area. The potential for tripping hazards should be considered when using GPR equipment. Worker fatigue may occur if a GPR unit is used over an extended period of time. The potential for exposure to low levels of non-ionizing radiation also may occur when using GPR. These conclusions are supported by the safety analysis done and the technology data safety sheet (TSDS) prepared by the International Union of Operating Engineers (IUOE) for demonstration of GPR at the WVDP.

Safety and Health Lessons Learned from Demonstrations

The potential for a trip or fall is increased if a worker watches a GPR display monitor while surveying an area using a GPR antenna. Using GPR equipment for extended periods can cause worker fatigue because of the combined weight of a GPR battery pack and console, about 18 lbs. A break is recommended after using GPR equipment for two hours to prevent worker fatigue from occurring. If an overhead area is going to be surveyed, two people are needed to operate GPR equipment: one person to lift the antenna and one person to operate the display monitor.

Comparison with Baseline and Alternative Technologies

Reviewing engineering drawing to locate embedded components involves no hazards. However, if the only drawings available for review are inaccurate or out of date, embedded components may not be accurately identified. This increases the risk of hitting an unidentified component during core boring operations.

Using electrical current to trace embedded components can increase the risk of hitting embedded components during core boring if the tracer signal has failed to accurately identify a component.

Using GPR technology provides an added measure of safety for personnel because it is an accurate, non-invasive technique that can be used to identify embedded components before core boring takes place.

SECTION 7
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The U. S. Federal Communications Commission (FCC) Order of July 12, 2002 required all existing operators of GPR equipment to register their equipment by October 15, 2002. The operator information to be provided to the FCC is specified in 47 CFR § 15.525. New regulations are being promulgated to control the uses of Ultra Wideband (UWB) transmitters, which includes ground-penetrating radar.

The U. S. Department of Labor, Occupational Health and Safety Administration (OSHA) has established non-ionizing radiation safety standards in 29 CFR 1910.97. The OSHA regulations in this part define the radiation protection guides for both the power density and energy density for non-ionizing electromagnetic radiation devices and occupational exposure as well as the warning requirements for using the devices.

Risks, Benefits, Environmental and Community Issues

The Ground Penetrating Radar is a passive system and is environmentally safe. When GPR is used with engineering prints, it enhances safety and therefore does not have any adverse socioeconomic impacts. There are no community issues associated with use of GPR.

SECTION 8
LESSONS LEARNED

Implementation Considerations

In order to prevent the GPR antenna from becoming contaminated, the area to be scanned should either be decontaminated or covered with a light gauge – low-density material, such as plastic or reinforced fabric. The size of the antenna will determine the minimum distance from any obstructions that can be physically scanned.

APPENDIX A

REFERENCES

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5. Shinn, J., Principle Investigator, "Tomographic Site Characterization Using CPT, ERT, and GPR," Innovative Technology Summary Report DOE/EM-0517, U. S. Department of Energy, Office of Environmental Management, Office of Science and Technology, April 2000.

6. West Valley Remote Handled Waste Facility engineering prints:
   911 - D - 441 Sheet 1 & 2 of 4, Rev O, "In Cell HVAC System Pre-Filter Arrangement."
   911 - D - 70 Sheet 1 of 3, Rev 2, "Utility Piping Systems Piping Arrangement at 1st Level."
   911 - D - 023 Sheet 1 of 1, Rev 2, "Piping & Instrument Diagram Waste Collection & Transfer System."
   911 - D - 062 Sheet 1 & 2 of 2, Rev 2, "Waste Collection & Transfer System Piping Drain Details."
   911 - D - 412 Sheet 1 of 1, Rev 1, 'Partial Plan at 1st Level Mechanical Layout."
   911 - D - 201 Sheet 1 of 4, Rev 0, "Main Grounding Plan"

APPENDIX B

ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
CFR	Code of the Federal Regulations
D&D	Decontamination and Decommissioning
DOE	U. S. Department of Energy
GPR	Ground Penetrating Radar
LSDDP	Large-Scale Demonstration and Deployment Project
WVDP	West Valley Demonstration Project